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ENERGY MEASUREMENTS

THE
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SENSING
LABORATORY
OPERATED FOR THE U.S.
DEPARTMENT OF ENERGY BY EG&G/EM

EGG-10282-1001
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JANUARY 1984

AN AERIAL RADIOLOGICAL SURVEY OF THE

OAK RIDGE RESERVATION

OAK RIDGE, TENNESSEE

DATE OF SURVEY: JUNE 1980

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Project Scientist

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T. P. Stuart, Manager
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This Document is UNCLASSIFIED

G P Stobie

G. P. Stobie
Classification Officer

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ABSTRACT

An aerial radiological survey of the Oak Ridge Reservation was conducted during June 1980 by EG&G Energy Measurements, Inc. for the United States Department of Energy (DOE). The survey consisted of airborne measurements of both natural and man-made gamma radiation from the terrain surface in and around the Oak Ridge Reservation. These measurements allowed a determination of the terrestrial spatial distribution of isotopic concentrations and equivalent gamma ray exposure rates from ^{60}Co, ^{234m}Pa, and ^{137}Cs. The results are reported as isopleths for the isotopes and are superimposed on scaled maps of the area. Gamma ray energy spectra are also presented for the net man-made radioelements.

This was the third aerial radiological survey of the entire Oak Ridge Reservation. The earlier surveys were conducted in 1973 and 1974.

All areas of man-made activity were in the same location as indicated by the results of the earlier surveys. It appears that no detectable new man-made activity has been released in the survey area since the 1973 and 1974 surveys.

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1.0 INTRODUCTION

The United States Department of Energy (DOE) established the Aerial Measuring System (AMS) to provide an aerial radiological surveillance capability. AMS is maintained and operated for DOE by EG&G Energy Measurements, Inc., an independent contractor. Since its inception in 1958, this continuing nationwide program has included radiological surveys of nuclear power plants, processing plants for nuclear materials, and research laboratories. AMS aircraft have been deployed to nuclear accident sites and in searches for lost radioisotopes. AMS aircraft also fly mapping cameras and multispectral camera arrays for aerial photography and thermal mappers for infrared imagery. All of the survey operations are conducted at the request of federal or state agencies and by direction of the DOE.

The aerial radiological survey of the Oak Ridge Reservation was conducted by EG&G/EM for the Office of Nuclear Safety. The survey was conducted during June 1980 and consisted of airborne measurements of both natural and man-made gamma radiation from the terrestrial surface in and around the plant site. This survey was the third for the Oak Ridge Reservation, the first two being conducted in 1973 and 1974.[1] Such surveys are part of a routine environmental surveillance program conducted by DOE.

2.0 SITE DESCRIPTION

DOE's Oak Ridge Reservation is located in Tennessee and contains three major operating facilities: (1) the Oak Ridge National Laboratory (ORNL, X-10 area), (2) the Oak Ridge Gaseous Diffusion Plant (ORGDP, K-25 area), and (3) the Y-12 Plant, all operated by the Nuclear Division of Union Carbide Corporation. Other smaller facilities, utilizing nuclear materials, are also located within the area.[2]

The DOE-owned area, about 150 km^2 (58 mi^2), is bounded on the south and west by the Clinch River and, generally, on the north and east by a fence line shown in Figure 1.

The Oak Ridge National Laboratory is a large laboratory facility dedicated to research, development, and production services in energy-related fields. The Laboratory's facilities consist of nuclear reactors, chemical pilot plants, research laboratories, radioisotope production laboratories, and support facilities. Low level discharges, primarily in the early years of the atomic energy program, have resulted in contaminants in the White Oak Creek and White Oak Lake areas. Many burial grounds also exist in the vicinity of the Laboratory.

The Oak Ridge Gaseous Diffusion Plant's primary mission is the enrichment of uranium hexafluoride in the ^{235}U isotope. This large industrial facility consists of 70 buildings used in production, research, and development. Minor quantities of radioactive materials are discharged to Poplar Creek.

The Oak Ridge Y-12 Plant performs four major functions: (1) production of nuclear weapon components, (2) fabrication support for weapon design agencies, (3) support for the Oak Ridge National Laboratory, and (4) support and assistance to other government agencies. A small amount of radioactive material, mostly normal and depleted uranium, is discharged to East Fork Poplar Creek and to Bear Creek.

The multiplicity of operations conducted at the Oak Ridge Reservation result in the following categories of surface, man-produced, gamma radiation observable from the air:

1. Radioactivity used in connection with the various activities of the facilities. This includes the thorium and the depleted, natural and enriched uranium sources at the Y-12 and ORGDP Plants, as well as the use of radioactive sources (including reactors) in the buildings and immediate vicinity of the ORNL and Y-12 Plants.

2. Radioactivity from waste storage and burial grounds. There are about 10 such areas located in and near the major facilities.

3. Radioactivity from ecology irradiation areas. Radioactivity is used to study radiation plant damage and as tracers in basic ecological research. Sixteen such areas have been used on the Oak Ridge Reservation.

4. Radioactivity from contaminated areas due to process water discharged directly into the streams or indirectly by drainage (or seepage) from or through waste storage, burial grounds or ecology irradiation areas.

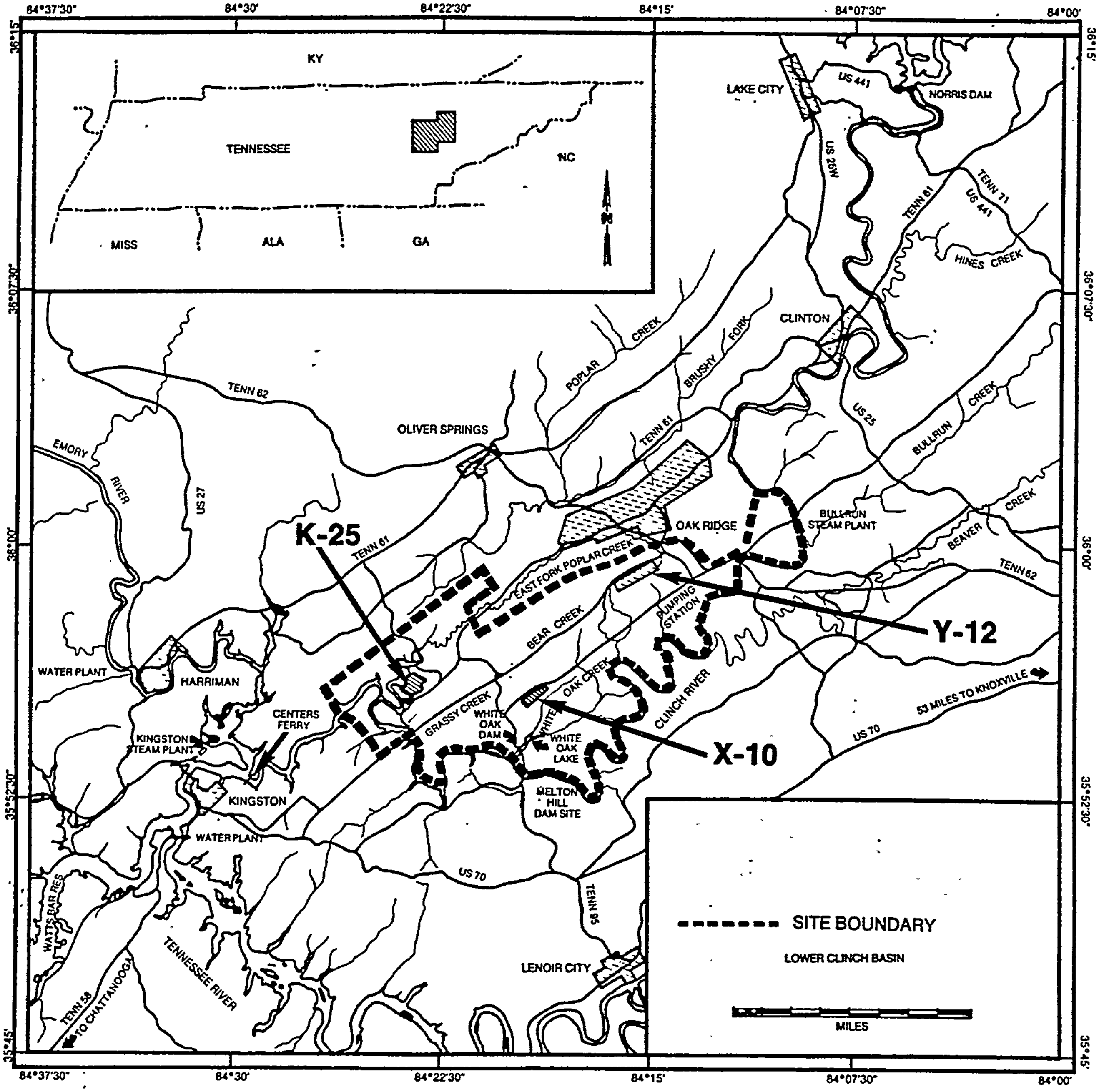


Figure 1. *DOE'S OAK RIDGE FACILITIES*

3.0 SURVEY PLAN

The general purpose of the airborne surveys of major DOE national laboratories and nuclear facilities is to provide data to assist DOE in identifying any radioactive contaminants and the corresponding concentrations and spatial distributions. The survey results provide data to assist in the effective management and control of all radioisotopes at each site. The measurement sensitivity and data processing procedures provide total area coverage with a broad overview and a detailed definition of the extent of gamma producing isotopes in specific areas. These results support the laboratories and facilities in assessing the environmental impact of their operations.

The data obtained during the aerial radiological surveys can be used as a basis for repeat surveys in case of an accident or incident in which any radioactivity is released into the environment (large-scale deposition). The AMS surveys are designed to cover large areas surrounding nuclear facilities. The gamma ray spectral data are processed to provide both a qualitative and quantitative analysis of the radionuclides in the survey area. A steering computer is programmed to set up a series of parallel flight lines to cover the survey area. During this survey, the aircraft was flown at a speed of 36 m per second (118 ft/sec), 91 m (300 ft) above the ground, along flight lines spaced at 152 m (500 ft) apart.

The survey covered an area of approximately 150 km^2 (58 mi^2) over the Oak Ridge Reservation. All data were scaled to overlay a 240 m per cm (2000 ft/in) TVA map (S-16A) of the Oak Ridge area (Figure 2). The data were analyzed for all man-made gamma ray emitting radionuclides and specifically for ^{60}Co, ^{234m}Pa and ^{137}Cs.

The actual flight lines flown by the helicopter are shown in Figure 3.

4.0 SURVEY EQUIPMENT

A Messerschmitt-Bolkow-Blohm (MBB) BO-105 helicopter (Figure 4) was used for the low altitude survey. The aircraft carried a crew of two and a lightweight, third generation version of the Radiation and Environmental Data Acquisition and Recorder (REDAR III) system. Two pods—each containing ten 12.7-cm diameter by 5.1-cm thick sodium iodide, NaI(Tl), detectors—were mounted on the sides of the helicopter.

The preamplifier signal from each detector was calibrated with a ^{22}Na source. Normalized outputs of each detector were combined in a ten-way summing amplifier for each array. The outputs of each array were matched and combined in a two-way summing amplifier. Finally, the signal was adjusted in the analog-to-digital converter (ADC) so that calibration peaks appeared in preselected channels of the multichannel analyzer of the REDAR.

4.1 REDAR System

REDAR is a multi-microprocessor, portable data acquisition and real-time analysis system. A block diagram of the REDAR system is shown in Figure 5. The system utilizes four low power microprocessors to process the data collected. The multichannel analyzer collects 1024 channels of gamma ray spectral data (4.0 keV/channel) once every second during the survey operation. The 1024 channels of data are sent to the single channel processor and are compressed into 256 channels with partitions. Table 1 summarizes the spectral data compression performed by REDAR.

The spectrum is divided into three partitions with the appropriate energy coefficient to make the width of the photopeaks approximately the same in each partition. The resolution of the NaI(Tl) crystals varies with energy, permitting the compression of the spectral data without compromising photopeak identification and stripping techniques. In the first partition (channels 0-75), the data are not compressed to permit stripping of low energy photopeaks, such as the 60 keV photopeak from ^{241}Am.

The spectral compression reduces the amount of data storage required by a factor of four.

The 256 channels of spectral data are continuously recorded each second. The REDAR system has two sets of spectral memories. Each memory can accumulate four individual spectra. The two memories are operated in a flip-flop mode, every 4 seconds, for continuous data accumulation. While one memory is being used to store data, the data in the other memory are being transferred to magnetic tape.

Two additional memories are used to store non-spectral data. They operate in the same flip-flop mode as the spectral memories. The non-spectral data consist of aircraft position, altitude, time of day, temperature, pressure, and special labels for data reduction purposes. Both gamma ray spectral and non-spectral data are acquired at 1-second intervals and recorded every 4 seconds on four-track cartridge tapes. The REDAR system has two tape recorders, each capable of recording approximately 1 hour of data. At the end of each tape, the system automatically switches to the other recorder. The REDAR system can run essentially unattended for 2 hours.

A display is available for real-time examination of the spectral data. The data can be displayed in the linear or compressed mode. The data can be reset, added to, or subtracted from the display without affecting the information recorded on tape.

The REDAR data acquisition system is shown in Figure 6.

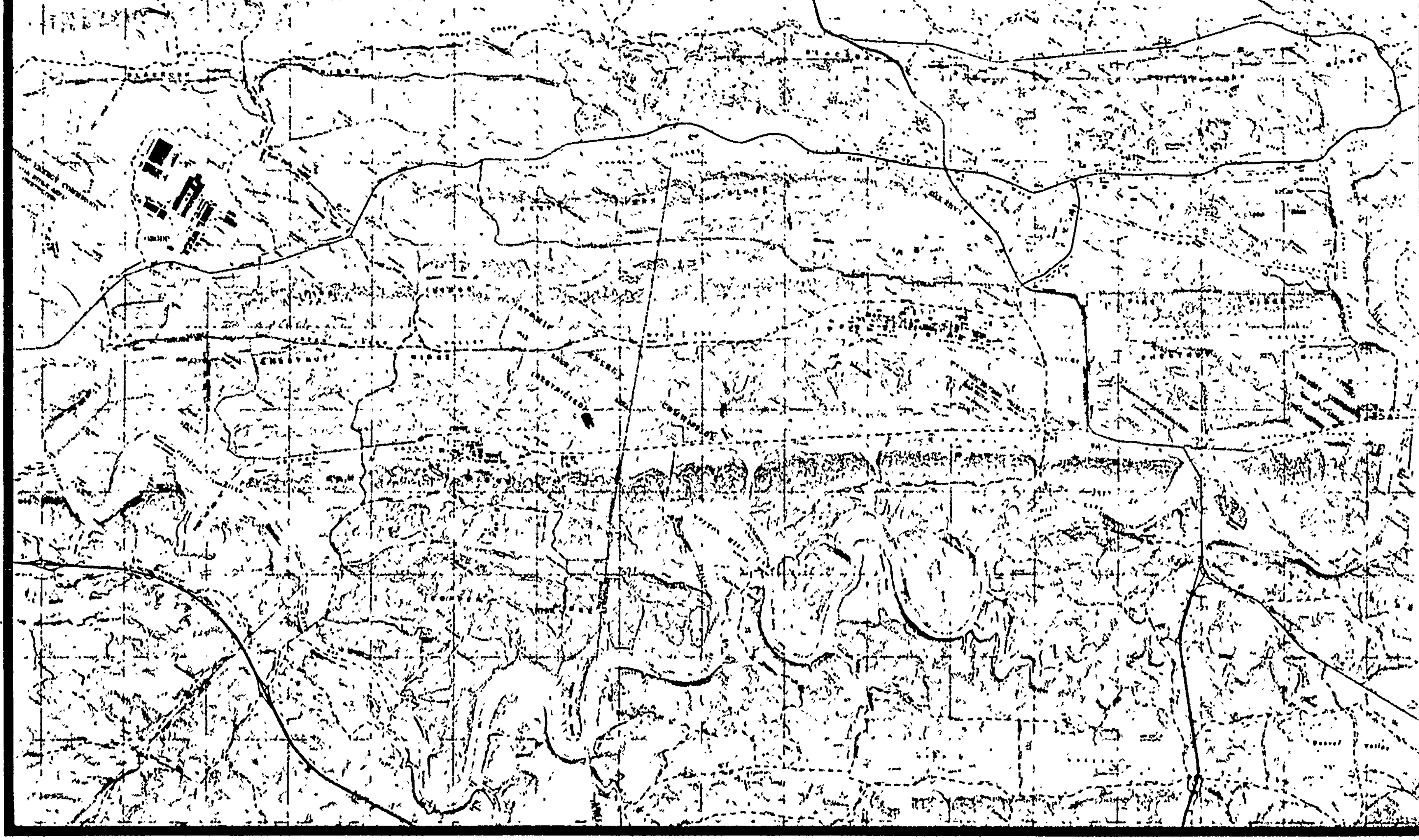


Figure 2. *TVA MAP (S-16A) OF THE OAK RIDGE RESERVATION*

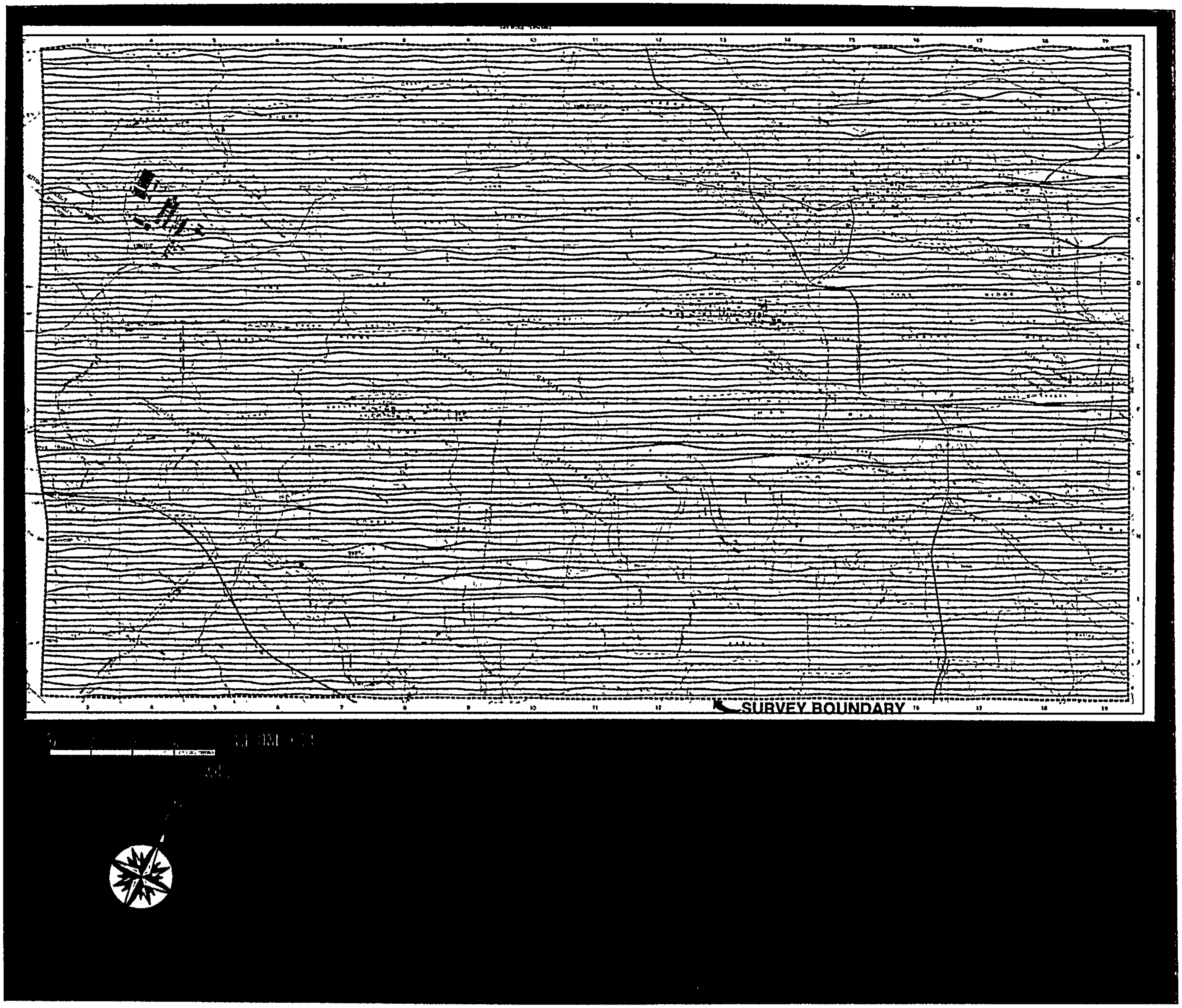


Figure 3. *FLIGHT LINES FLOWN BY THE HELICOPTER*

Figure 4. *MBB BO-105 HELICOPTER WITH DETECTOR PODS*

REDAR III single channel (SC) is defined as any specified number of contiguous channels derived from the 1024 channel pulse height analyzer before compression. The address (location) and width (number of channels) can be selected from a front panel keyboard. All parameters are loaded to default values which are those most likely to be optimal.

Five SC's are available in both digital format on the alphanumeric display and in analog voltages on the digital-to-analog converter (DAC) outputs. The digital and analog displays may be keyboard-assigned and modified, as required.

The DAC's are 8 bit (256 counts) full scale per time interval (200 milliseconds), which gives a maximum capability of 1280 counts per second—full scale. If the anticipated or measured count rate exceeds this value, the incoming rate can be divided (prescaled) by any integer value from 1 to 256 to set the reading on scale as desired. The system will again set values close to optimal upon power up with the DAC outputs defined as SC_1 out on DAC_0, SC_2 out on DAC_1, etc. Again, these may be reassigned by the keyboard if necessary.

These five analog outputs may then be displayed upon multipen strip chart recorders or input to an analog matrix panel for further processing. The matrix panel will perform the following algorithms upon these values to enhance real-time detection capability:

1. Each channel may be multiplied by a constant (K) from 0.1 to 10.1.

$$\text{OUTPUT} = (K_x)\ (SC_x)$$

2. Each channel may be added to or subtracted from any other two channels.

$$\sum_{1}^{3} = \pm [(K_x)\ (SC_x)] \pm [(K_1)\ (SC_1)] \pm [(K_2)\ (SC_2)]$$

3. Each summation generated in step two can be added to or subtracted from another summation.

$$\text{Output} = \pm \sum_{1}^{3}{}_{x} \pm \sum_{1}^{3}{}_{1} \pm \sum_{1}^{3}{}_{2}$$

4. To fit mission requirements, these outputs can then be applied to a switch selectable time constant circuit to apply filters from 0.2 to 16 seconds.

4.2 Helicopter Positioning Method

The helicopter position was established by two systems: a microwave ranging system (MRS)* and an AL-101 radar altimeter. The MRS master station, mounted in the helicopter, interrogated two remote transceivers which were mounted on towers outside the survey area. By measuring the round-trip propagation time between the master and remote stations, the master unit computed the distance to each. The distances were recorded on magnetic tape each second. In subsequent computer processing these distances were converted to position coordinates.

The radar altimeter similarly measured the time lag for the return of a pulsed signal and converted this delay to aircraft altitude. For altitudes up to 1500 m the accuracy was ±0.6 m or ±2%, whichever was greater. These data were also recorded on magnetic tape so that any variation in gamma signal strength caused by altitude fluctuation could be compensated.

The detectors and electronics systems which accumulated and recorded the data are described in considerable detail in a separate publication.[3]

*Trisponder/202A, Del Norte Technology, Inc., Euless, Texas.

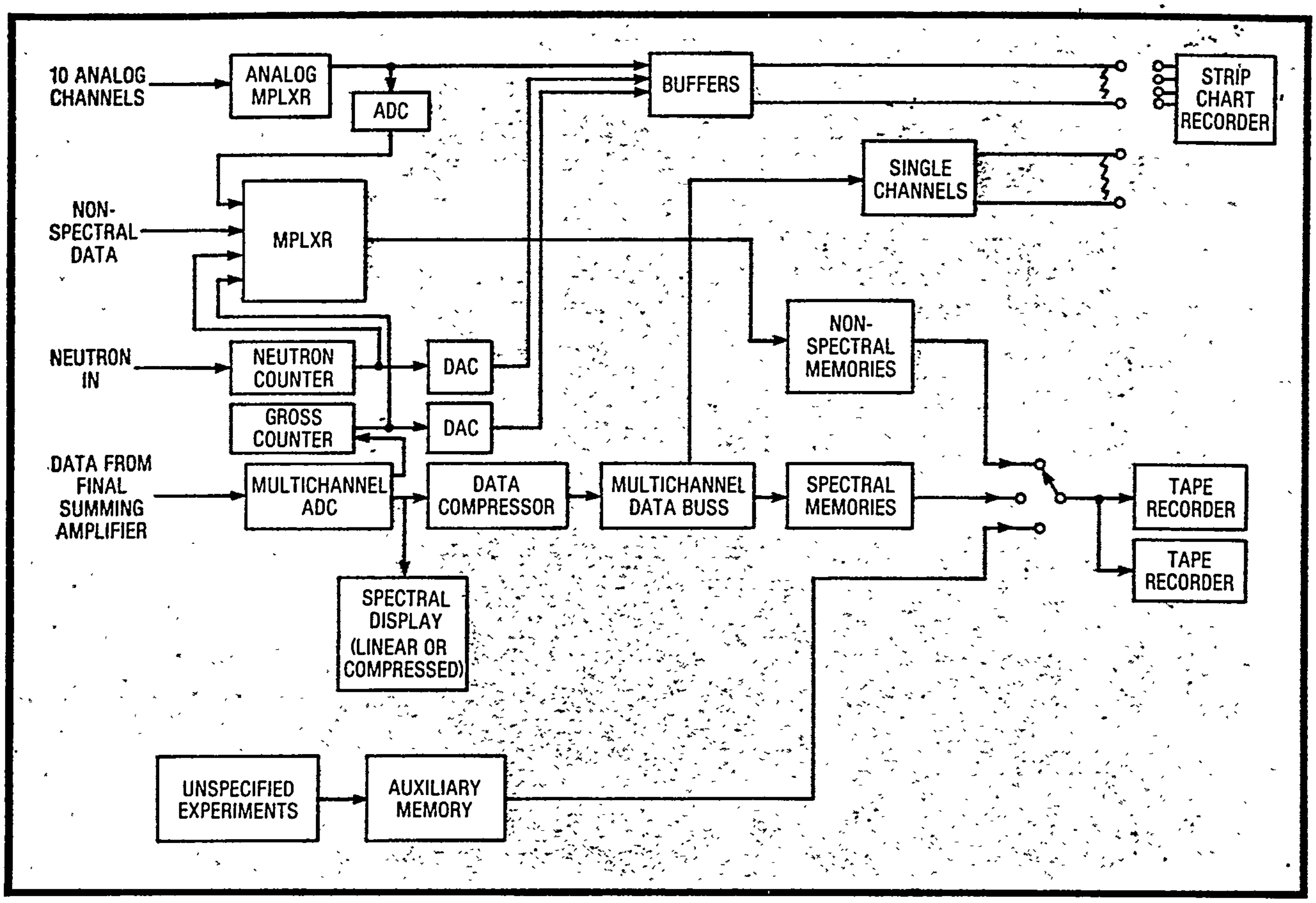


Figure 5. *REDAR SYSTEM BLOCK DIAGRAM*

5.0 DATA PROCESSING

Data processing was begun in the field with the Radiation and Environmental Data Analyzer and Computer (REDAC) system. This system is a computer analysis laboratory mounted in a mobile van. The interior of the van is shown in Figure 7.

During the survey operations, the van and aircraft were based at the Maryville Airport in Maryville, Tennessee.

The REDAC system consists primarily of two Cipher Data Products tape drives, a Data General NOVA 840 computer, two CalComp plotters, a

Table 1. REDAR III Spectral Data Compression

Eγ (keV)	Channel Input	Energy Coefficient ΔE (keV/channel)	Compressed Channel Output
0 - 300	0 - 75	4	0 - 75
304 - 1620	76 - 405	12	76 - 185
1624 - 4068	406 - 1017	36	186 - 253
4072 - 4088	1018 - 1022	N/A	254
>4088 - Analog Cutoff	1023	N/A	255
	1024	Unused	256

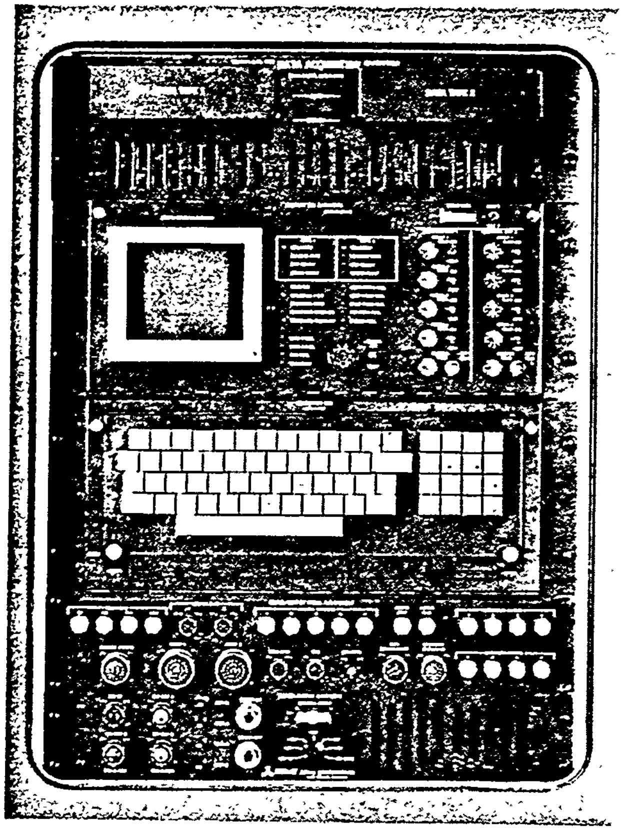


Figure 6. *REDAR DATA ACQUISITION SYSTEM*

Figure 7. *REDAC DATA REDUCTION SYSTEM MOUNTED INSIDE A MOBILE VAN*

Texas Instruments thermal terminal, and a Tektronix CRT display screen with a hard copier. A block diagram of the system is shown in Figure 8. The computer has a 64 kbyte memory with an additional 2.5 Mbyte disc storage. An extensive set of software routines is available for data processing.

Gamma spectral windows can be selected for any portion of the spectrum. Weighted combinations of such windows can be summed or subtracted and the result plotted as a function of time or position. By the proper selection of windows and weighting factors, it is possible to extract the photopeak count rate for radioisotopes deposited on the terrain by human activity. Such isotopes disturb the natural pattern of soil radioactivity. These photopeak count rates can then be converted to isotope concentrations or exposure rates. Spectral data can be summed over any portion of a survey flight line.

The spectral data can be decompressed into a linear plot. The REDAC displays the linear spectral data or plots it on the incremental plotter for isotopic identification.

6.0 DATA ANALYSIS

The aerial radiation data consisted, in general, of contributions from the naturally occurring radioelements, aircraft and detector background, and cosmic rays. For this survey, the major emphasis was placed on extracting that component arising from man-made radioactivity. Isopleth maps were produced by processing the data in different ways: gross count, man-made gross count (MMGC), and ^{60}Co, ^{234m}Pa and ^{137}Cs photopeak count rate extractions.

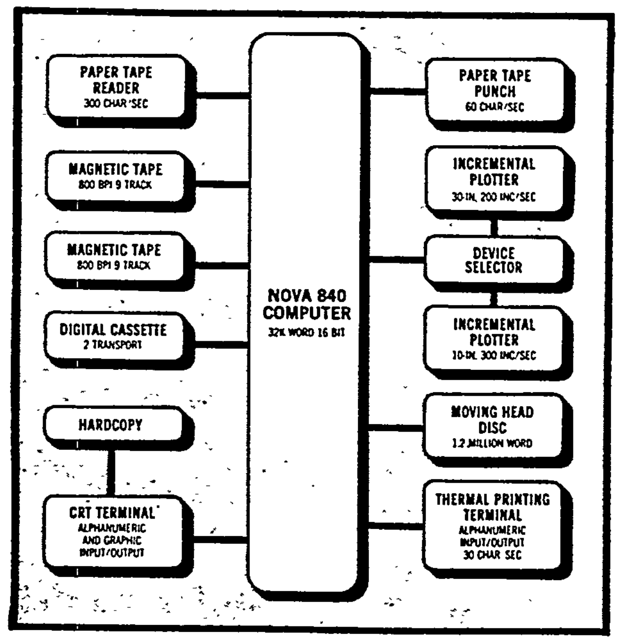


Figure 8. *REDAC ANALYSIS SYSTEM BLOCK DIAGRAM*

6.1 Gross Count

The gross count method was based on the integral counting rate in that portion of the energy spectrum between 0.05 MeV and 3.0 MeV. This count rate (measured at survey altitude) was converted to exposure rate at 1 m above ground level by application of a predetermined conversion factor. This factor assumes a uniformly distributed source covering an area which is large compared with the field-of-view of the detector (> 400 meters) at the survey altitude of 91 meters. For a finite source distribution which is small compared to the field-of-view of the detector system, it is necessary to modify the exposure rate values by utilizing the data in Table 2. The exposure rate values could be one to two orders of magnitude higher for an area with a source localized in a small area.

Table 2. Correction Factors Versus Area of Contamination

Diameter of Contaminated Circular Area (meters)	Correction Factor
10	300
25	60
50	18
100	5.0
200	2.4
300	1.7
400	1.5
∞	1.0

6.2 Man-Made Gross Count

The MMGC rate algorithm is designed to sense the presence of changes in spectral shape. Large changes in gross counting rates from natural radiation usually produce only small changes in spectral shape because the natural emitters change in more or less constant ratio as the detector moves from one location to another. The algorithm senses counts in the lower portion of the spectrum in excess of those predicted on the premise that these counts bear a constant ratio to counts in the upper portion. Since the algorithm is designed to be most sensitive to man-made nuclides, the spectrum dividing line is chosen at an energy (1.4 MeV) above which most long-lived, man-made nuclides do not emit gamma rays. It is analytically expressed in MeV as:

$$\text{MMGC} = \sum (0.05 - 1.39) - K \sum (1.40 - 3.00)$$

The counts in the upper energy window (1.40 to 3.00 MeV) are multiplied by a constant, K, to equal the counts in the lower energy window (0.05 to 1.39 MeV) and the resultant MMGC is equal to zero for areas containing normal background radiation.

Spectral data from the survey revealed that all of the gamma rays from the man-made isotopes had energies less than 1.4 MeV. Therefore, the MMGC extraction technique was used to locate man-made activity in the survey area.

The man-made gross count algorithm is general and will respond to a wide range of nuclides. The result of using this generality is the lack of sensitivity to specific nuclides. If the search nuclide is known, more sensitive algorithms can be devised.

6.3 Photopeak Count Rate Extraction

Four windows were set up to extract the photopeak count rates for ^{60}Co, ^{234m}Pa and ^{137}Cs. The windows were: ^{60}Co (1250 to 1394 keV), ^{234m}Pa (914 to 1070 keV), ^{137}Cs (576 to 734 keV) and natural background (1394 to 3000 keV).

Photo count rate extraction equations for:

$$\text{Natural Background} = K_B \sum_{1394}^{3000}$$

K_B = ratio of the counts in 1394 to 3000 keV window to the number of counts in 50 to 1394 keV window.

$$^{60}\text{Co} = \sum_{1250}^{1394} - K_{BCo} \sum_{1394}^{3000}$$

K_{BCo} = number of counts from natural background that appear in ^{60}Co photopeak window.

$$^{234m}Pa = \sum_{914}^{1070} - K_{CoPa} \sum_{1250}^{1394} - K_{BPa} \sum_{1394}^{3000}$$

K_{CoPa} = number of counts from ^{60}Co that appear in the ^{234m}Pa window.

K_{BPa} = number of counts from natural background that appear in the ^{234m}Pa window.

$$^{137}Cs = \sum_{576}^{734} - K_{PaCs} \sum_{914}^{1070} - K_{CoCs} \sum_{1250}^{1394}$$

$$- K_{BCs} \sum_{1394}^{3000}$$

K_{PaCs} = number of counts from ^{234m}Pa that appear in the ^{137}Cs window.

K_{CoCs} = number of counts from ^{60}Co that appear in the ^{137}Cs window.

K_{BCs} = number of counts from natural background that appear in the ^{137}Cs window.

The constants were determined by obtaining a "pure" spectrum of the individual isotopes from various regions of the survey area. The "pure" spectrum is obtained by using the upper energy window (1.40 to 3.00 MeV) to normalize the source spectrum with a background spectrum. Subtracting the background produces a net "pure" spectrum of the isotope. The extraction coefficients can be determined from a "pure" spectrum of the individual isotopes of interest.

Table 3 gives the correction factor for finite ^{60}Co, ^{234m}Pa, and ^{137}Cs sources which are smaller than the field-of-view of the detector system.

6.4 Minimum Detectable Activity

Table 4 indicates the minimum detectable activity for several isotopes as a function of source geometry for the aerial system used in the Oak Ridge survey. The radioactivity was assumed to

Table 3. Source Correction Factors Versus Radius of a Finite Source

Radius (meters)	Correction Factor		
	^{60}Co	^{234m}Pa	^{137}Cs
10	60	57	51
25	14	13	12
50	4.1	3.9	3.6
100	1.7	1.6	1.5
200	1.1	1.1	1.1
400	1.0	1.0	1.0

be distributed exponentially with depth in the soil according to the following equation:

$$S_v = S_v^0 \, e^{-\alpha z}$$

where

S_v^0 = the soil activity per gram at the surface
S_v = the soil activity per gram at a depth z, and
α = the reciprocal of the relaxation depth.

The total activity per unit area can then be written as:

$$S_A = \rho \int_0^\infty S_v dz = \left(\frac{S_v^0}{\alpha}\right) \rho$$

where ρ is the soil density.

It was assumed in Table 4 that no additional shielding existed between the source and the detector array. It was further assumed that distributed sources were spread over an area comparable to several times the survey altitude.

7.0 RESULTS

7.1 Gross Count Exposure Rate Isopleth

The terrestrial exposure rate isopleth (Figure 9) is superimposed on a TVA map (S-16A) of the Oak Ridge Reservation. The exposure rates are expressed in units of microroentgens per hour (μR/h) at 1 m above ground level. The isopleth includes a cosmic ray exposure rate of 3.8 μR/h. The gross count exposure rate isopleth is the total exposure rate from natural radionuclides in the soil, man-made sources, and cosmic rays.

Table 4. Minimum Detectable Activity for Several Selected Radioisotopes as a Function of Source Geometries[a]			
	Surface Sources		
Isotope	Point Source (mCi)	Distributed Source (μCi/m²) $\alpha = 0$	Volume Source $\left(\frac{pCi}{g}\right)^{b}$ $\alpha = 10$ cm
^{60}Co	4.1	0.11	1.4
^{234m}Pa	700.0	20.0	263.0
^{137}Cs	7.9	0.25	3.7

[a] Assuming a survey altitude of 91 meters.

[b] Conversion factor to pCi/g relates to the average value of a 5-cm deep soil sample.

7.2 Man-Made Gross Count Isopleth

Figure 10 is the MMGC isopleth expressed in counts per second. The count rate is an indicator of the magnitude of the intensity of the sources. The numbered sections on the isopleth are regions where spectral data have been extracted.

A net spectrum over an anomalous radiation area is obtained by removing the natural background from the spectrum. This is accomplished by using the high energy window (1.40 to 3.00 MeV) as a background monitor. A background spectrum is accumulated in an area that does not indicate man-made activity. After normalizing the spectrum over the area of interest and the background spectrum with the high energy window, the data are subtracted. The result is a net spectrum of man-made activity.

Figures 11 through 30 are the net spectra from Areas 1 through 20. The photopeaks are labeled with energy and most probable isotope responsible for the man-made activity. Other isotopes may also be present in these areas, but in much lower concentrations than the prominent isotopes identified. The man-made activity in Area 1 is negative because of the presence of a high concentration of ^{208}Tl. According to personnel at Oak Ridge, this area is used as a scrap thorium storage facility.

7.3 Photopeak Count Rate Isopleths

Table 5 can be used to convert the photopeak count rate to the appropriate radionuclide concentration, depending on the geometry of the source.

Figure 31 is the photopeak count rate due to ^{60}Co.

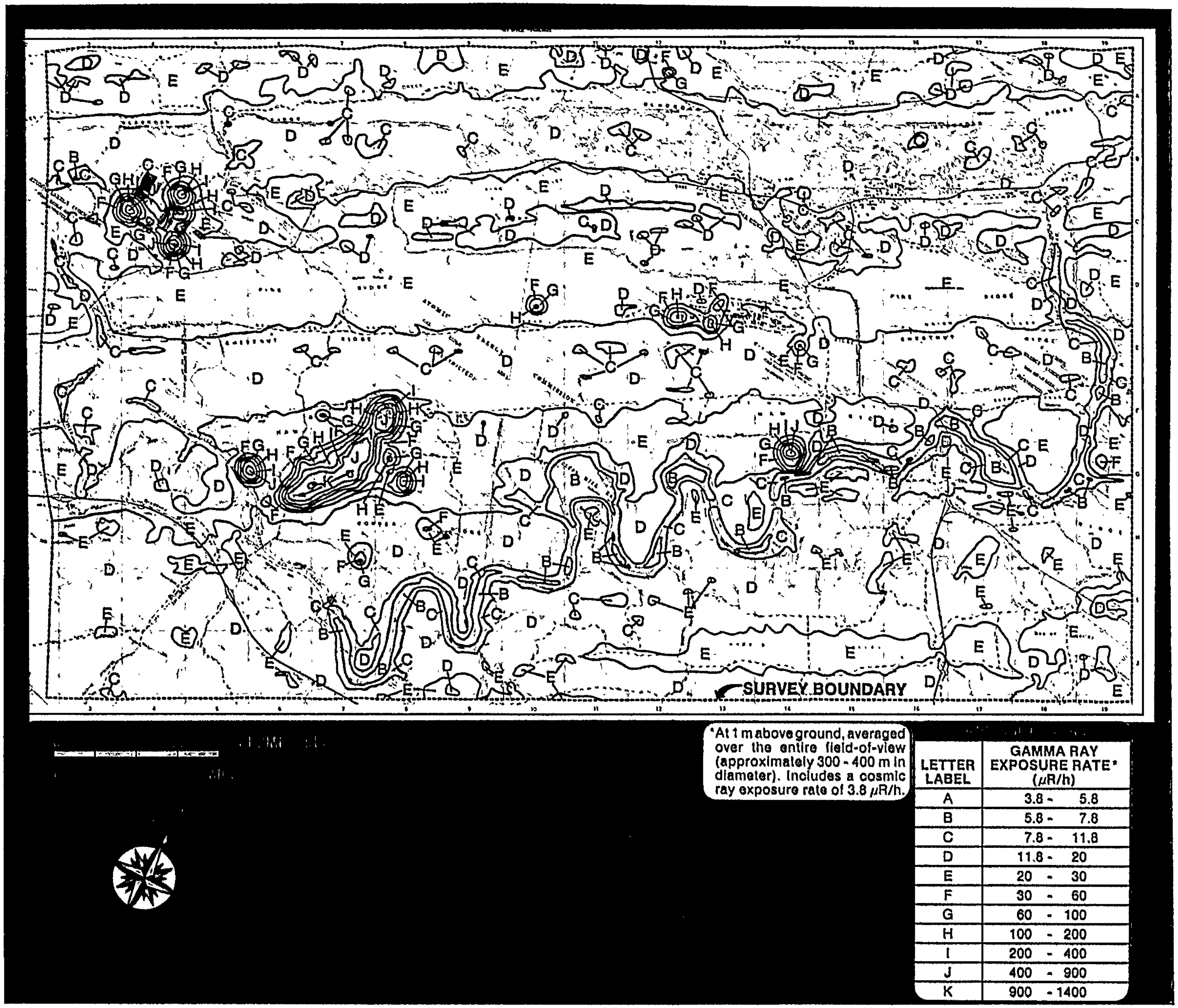
Figure 32 is the photopeak count rate due to ^{234m}Pa.

Figure 33 is the photopeak count rate due to ^{137}Cs.

8.0 SUMMARY

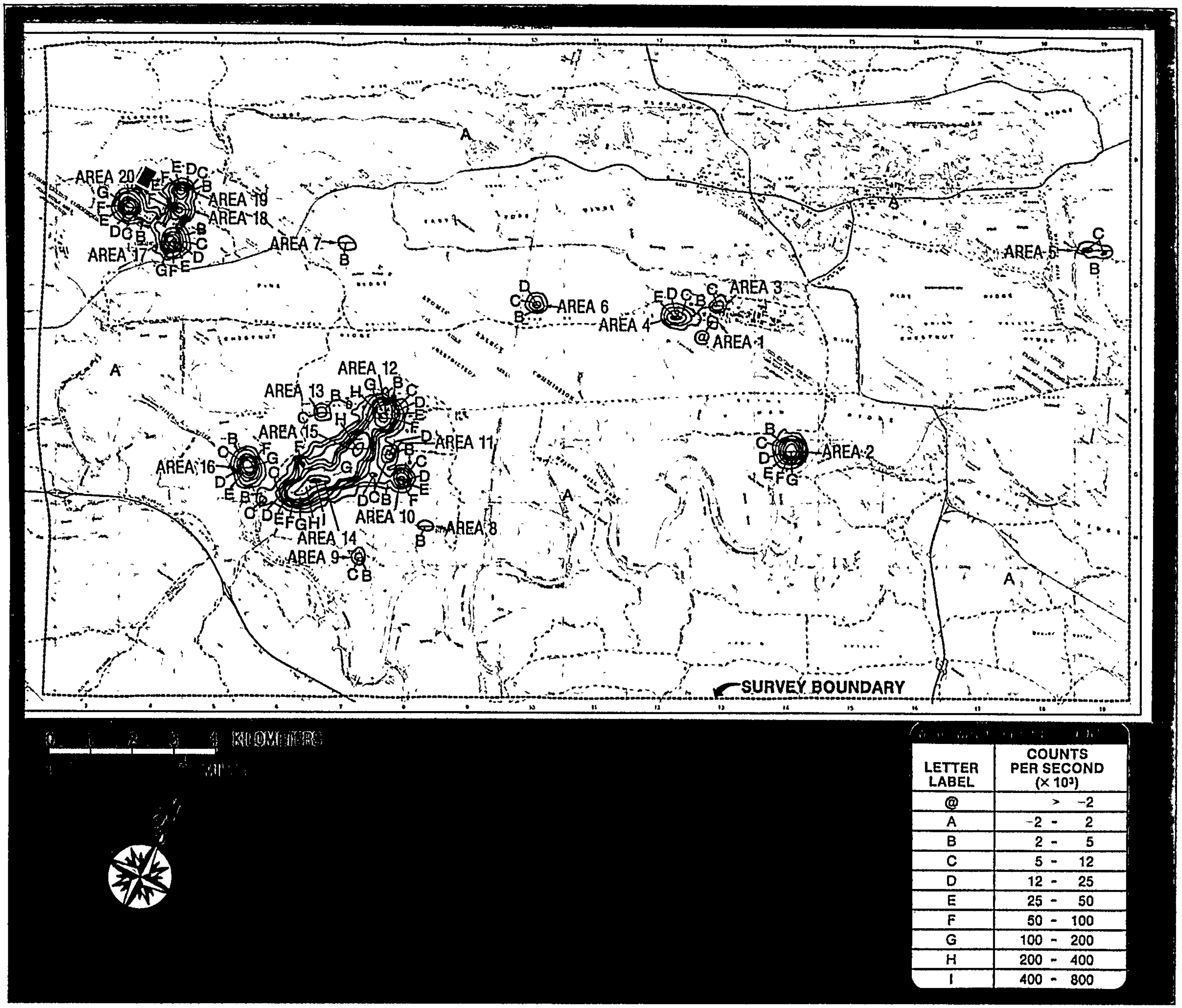
The survey results indicate the presence of ^{60}Co, ^{234m}Pa and ^{137}Cs. The ^{234m}Pa is a daughter product in the decay chain of uranium. The major portion of the activity was detected over buildings which are known storage and working areas. The activity in the buildings is part of the normal operations at the Oak Ridge Reservation.

No man-made activity associated with the operation of the Oak Ridge Reservation was found outside the site boundaries. The man-made activity found in Area 5 is not associated with DOE operations, according to personnel at Oak Ridge. Co-60



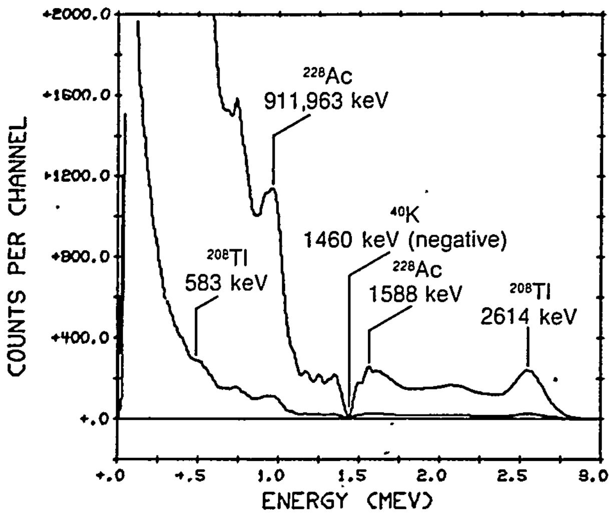
LETTER LABEL	GAMMA RAY EXPOSURE RATE* (μR/h)
A	3.8 - 5.8
B	5.8 - 7.8
C	7.8 - 11.8
D	11.8 - 20
E	20 - 30
F	30 - 60
G	60 - 100
H	100 - 200
I	200 - 400
J	400 - 900
K	900 - 1400

Figure 9. *TERRESTRIAL EXPOSURE RATE ISOPLETH*



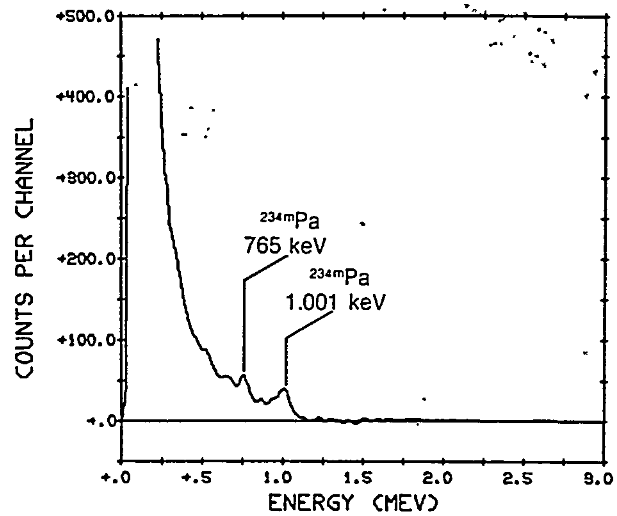
LETTER LABEL	COUNTS PER SECOND ($\times 10^3$)
@	> −2
A	−2 - 2
B	2 - 5
C	5 - 12
D	12 - 25
E	25 - 50
F	50 - 100
G	100 - 200
H	200 - 400
I	400 - 800

Figure 10. *MAN-MADE GROSS COUNT RATE ISOPLETH*



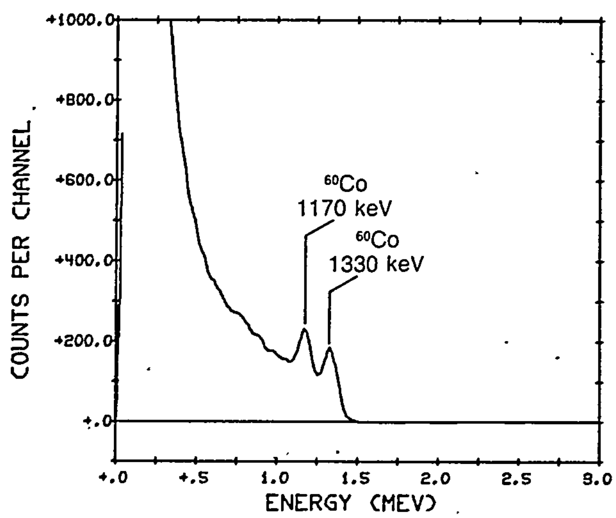
SPECTRUM NO. 145(86,88)-2(76,78)
DATE 6/7/80
LIVE TIME (MIN) +.558
INTEGRATED CT. +.1596497E+06
TYPE ORNL,LINE=-9,LOW SPOT,NET
ALTITUDE 300 FT.
AIRCRAFT BO-105

Figure 11. *NET SPECTRUM FROM AREA 1*



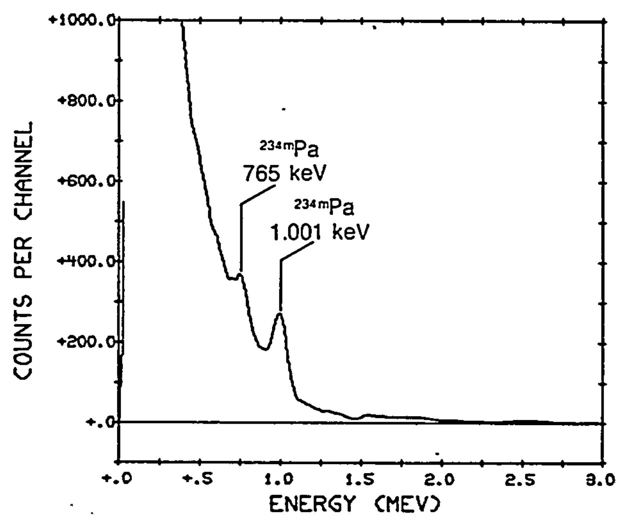
SPECTRUM NO. 152(112,113)-(116,117)
DATE 6/7/80
LIVE TIME (MIN) +.127
INTEGRATED CT. +.8618968E+05
TYPE ORNL,LINE=-12,#3HS NET
ALTITUDE 300 FT.
AIRCRAFT BO-105

Figure 13. *NET SPECTRUM FROM AREA 3*



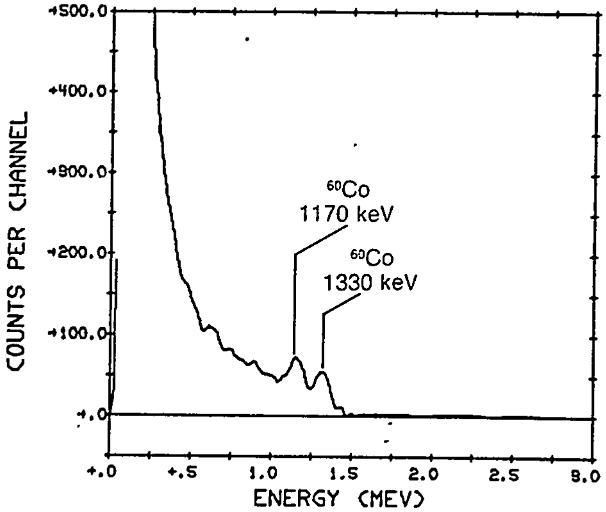
SPECTRUM NO. 322(64,70)-.647(86,95)
DATE 6/10/80
LIVE TIME (MIN) +.406
INTEGRATED CT. +.3863797E+06
TYPE ORNL,LINE=12,#1 HS,NET
ALTITUDE 300 FT.
AIRCRAFT BO-105

Figure 12. *NET SPECTRUM FROM AREA 2*



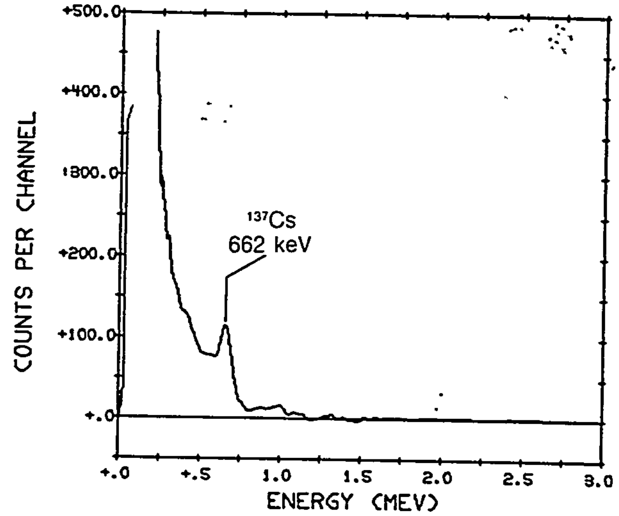
SPECTRUM NO. 148(105,110)-125,130)
DATE 6/7/80
LIVE TIME (MIN) +.337
INTEGRATED CT. +.4221690E+06
TYPE ORNL,LINE=-10,#2HS NET
ALTITUDE 300 FT.
AIRCRAFT BO-105

Figure 14. *NET SPECTRUM FROM AREA 4*



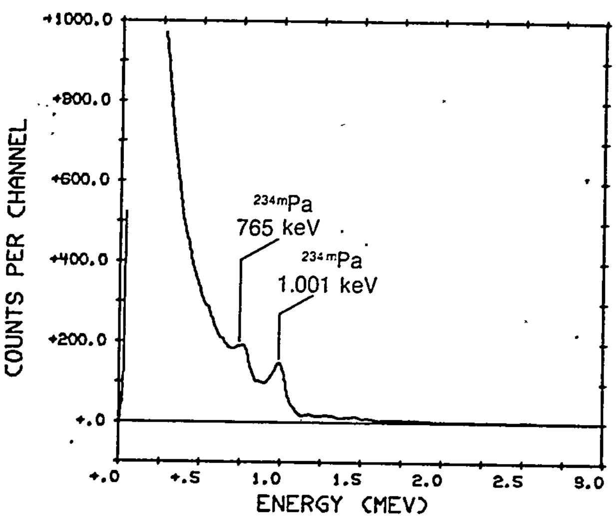
SPECTRUM NO. 186,(13,18)-(23,28)
DATE 6/7/80
LIVE TIME (MIN) +.374
INTEGRATED CT. +.1026530E+06
TYPE ORNL,LINE=-21,*1HS NET
ALTITUDE 300 FT.
AIRCRAFT BO-105

Figure 15. *NET SPECTRUM FROM AREA 5*



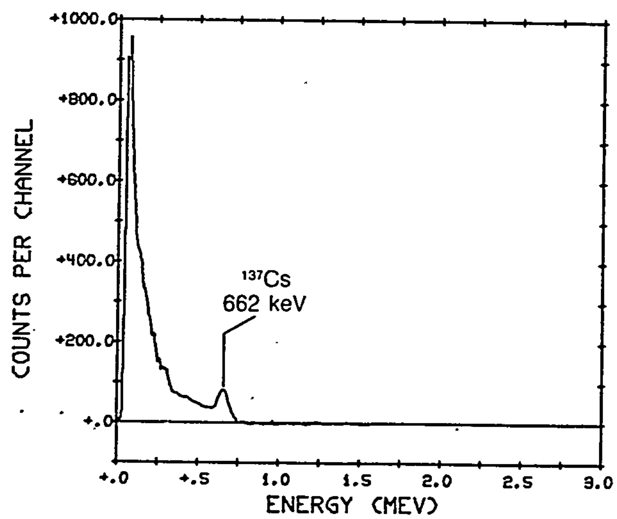
SPECTRUM NO. 489(51,55)-(71,75)
DATE 6/11/80
LIVE TIME (MIN) +.311
INTEGRATED CT. +.8906700E+05
TYPE ORNL,LINE=-22,*2HS NET
ALTITUDE 300 FT.
AIRCRAFT BO-105

Figure 17. *NET SPECTRUM FROM AREA 7*



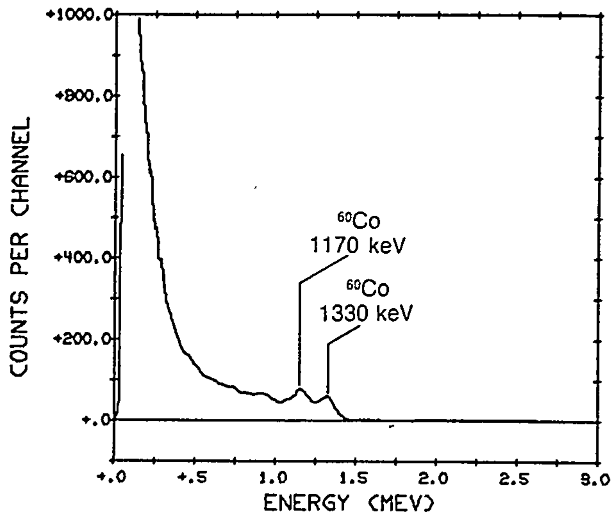
SPECTRUM NO. 152,(82,86)-(72,76)
DATE 6/7/80
LIVE TIME (MIN) +.317
INTEGRATED CT. +.2192594E+06
TYPE ORNL,LINE=-12,*1HS NET
ALTITUDE 300 FT.
AIRCRAFT BO-105

Figure 16. *NET SPECTRUM FROM AREA 6*



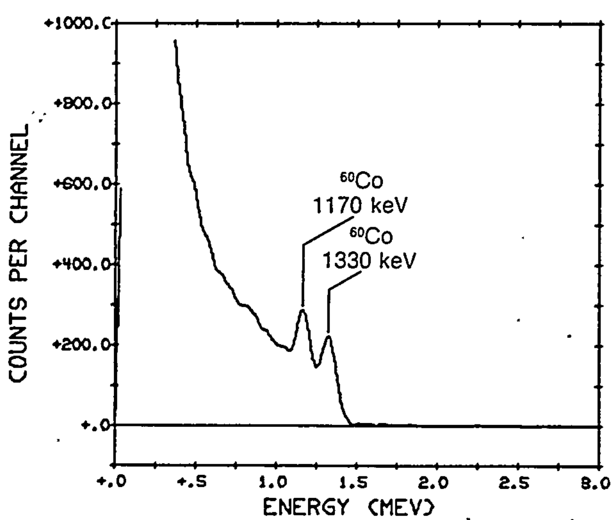
SPECTRUM NO. 361(54,56)-(67,69)
DATE 6/10/80
LIVE TIME (MIN) +.193
INTEGRATED CT. +.3362502E+05
TYPE ORNL,LINE 23,HS NET
ALTITUDE 300 FT.
AIRCRAFT BO-105

Figure 18. *NET SPECTRUM FROM AREA 8*



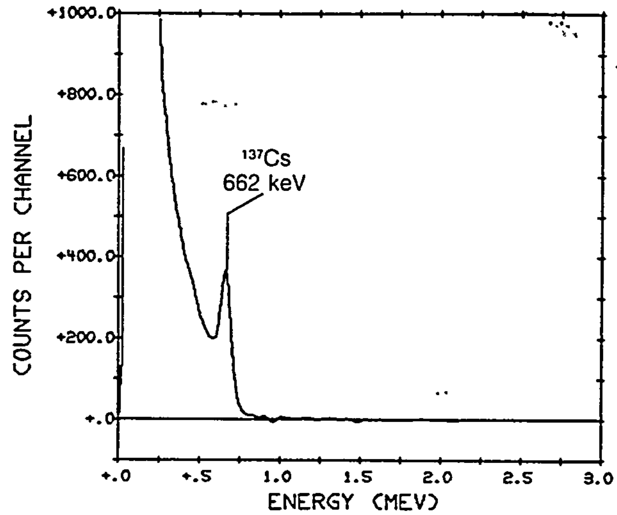
SPECTRUM NO. 380(134,137)-(142,145)
DATE 6/10/80
LIVE TIME (MIN) +.247
INTEGRATED CT. +.9299175E+05
TYPE ORNL,LINE=28,HS NET
ALTITUDE 300 FT.
AIRCRAFT BO-105

Figure 19. *NET SPECTRUM FROM AREA 9*



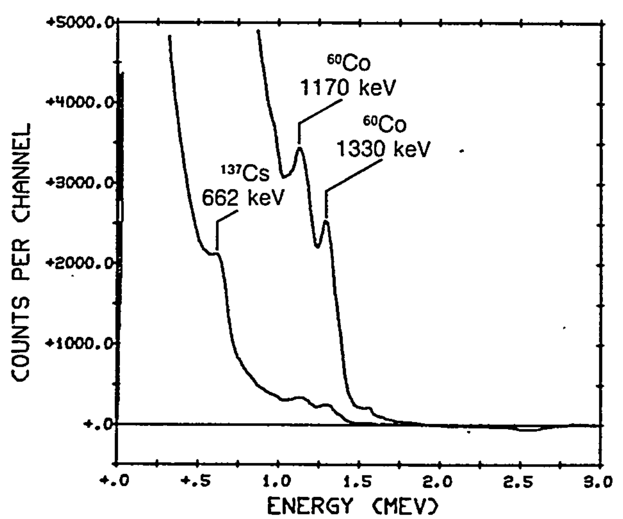
SPECTRUM NO. 337(61,63)-(74,76)
DATE 6/10/80
LIVE TIME (MIN) +.149
INTEGRATED CT. +.3749406E+06
TYPE ORNL,LINE=15,#3HS NET
ALTITUDE 300 FT.
AIRCRAFT BO-105

Figure 20. *NET SPECTRUM FROM AREA 10*



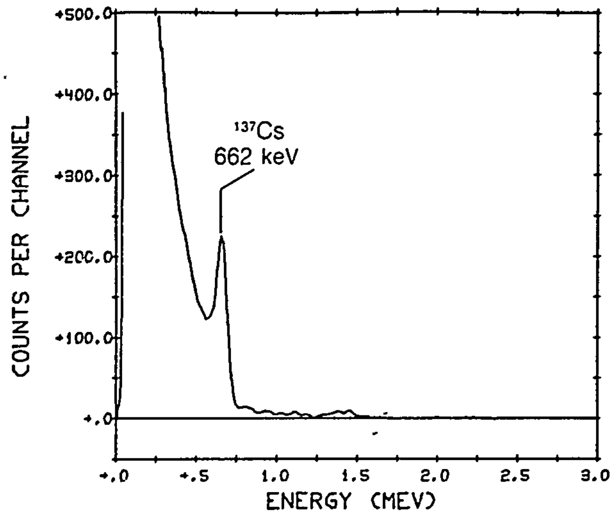
SPECTRUM NO. 322(131,133)-(121,123)
DATE 6/10/80
LIVE TIME (MIN) +.168
INTEGRATED CT. +.1975926E+06
TYPE ORNL,LINE=12,#2HS NET
ALTITUDE 300 FT.
AIRCRAFT BO-105

Figure 21. *NET SPECTRUM FROM AREA 11*



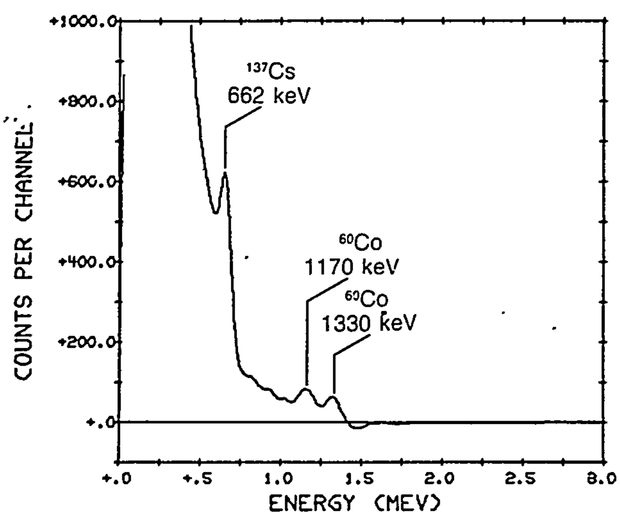
SPECTRUM NO. 290,(143,152)-(123,132)
DATE 6/9/80
LIVE TIME (MIN) +.483
INTEGRATED CT. +.1371351E+07
TYPE ORNL,LINE=5,#1HS NET
ALTITUDE 300 FT.
AIRCRAFT BO-105

Figure 22. *NET SPECTRUM FROM AREA 12*



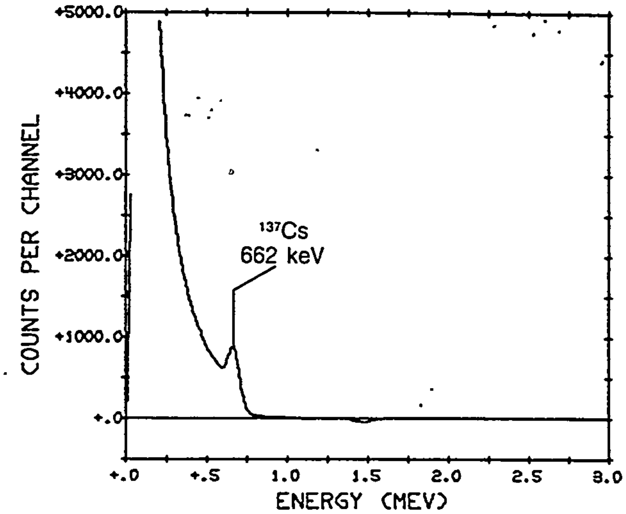
SPECTRUM NO. 290(157,160)-.383(123,132)
DATE 6/9/80
LIVE TIME (MIN) +.245
INTEGRATED CT. +.1032919E+06
TYPE ORNL,LINE=5,#2 HS,NET
ALTITUDE 300 FT.
AIRCRAFT BO-105

Figure 23. *NET SPECTRUM FROM AREA 13*



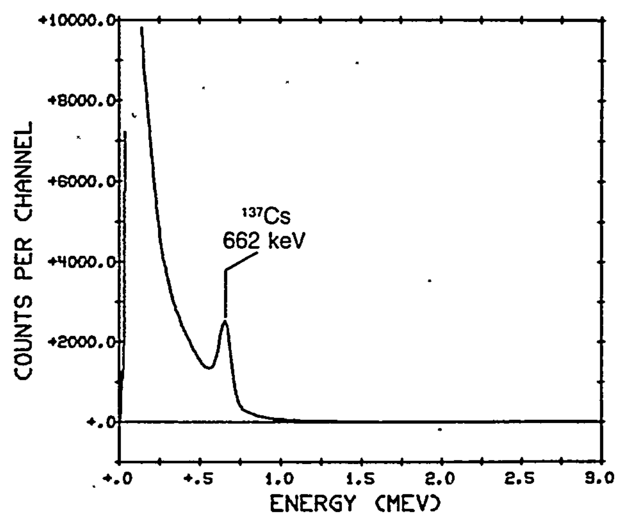
SPECTRUM NO. 345(43,38)-(63,68)
DATE 6/10/80
LIVE TIME (MIN) +.297
INTEGRATED CT. +.7723129E+06
TYPE ORNL,LINE=19,HS NET
ALTITUDE 300 FT.
AIRCRAFT BO-105

Figure 24. *NET SPECTRUM FROM AREA 14*



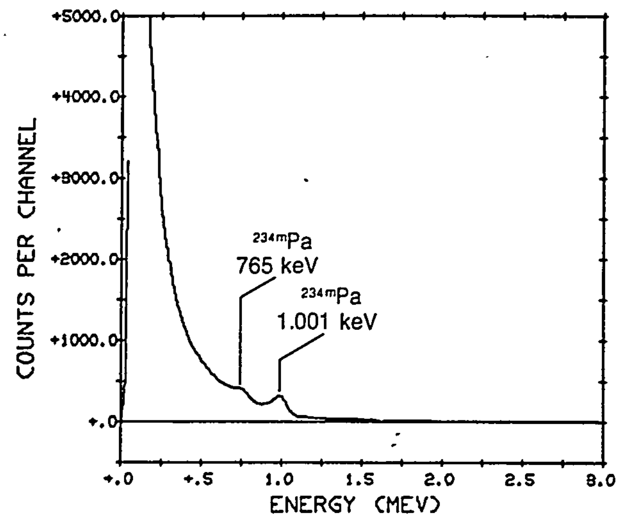
SPECTRUM NO. 314(50,55)-(70,75)
DATE 6/10/80
LIVE TIME (MIN) +.289
INTEGRATED CT. +.8117890E+06
TYPE ORNL,LINE=9,HS NET
ALTITUDE 300 FT.
AIRCRAFT BO-105

Figure 25. *NET SPECTRUM FROM AREA 15*



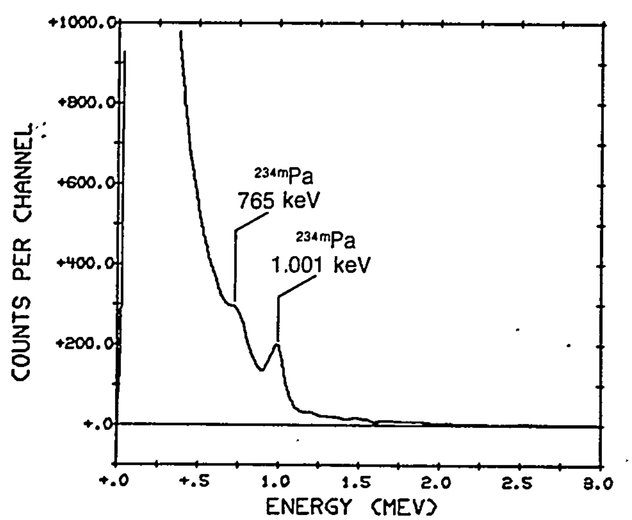
SPECTRUM NO. 335(153,157)-.264(168,180)
DATE 6/10/80
LIVE TIME (MIN) +.219
INTEGRATED CT. +.9273250E+06
TYPE ORNL,LINE=14,#2HS NET
ALTITUDE 300 FT.
AIRCRAFT BO-105

Figure 26. *NET SPECTRUM FROM AREA 16*



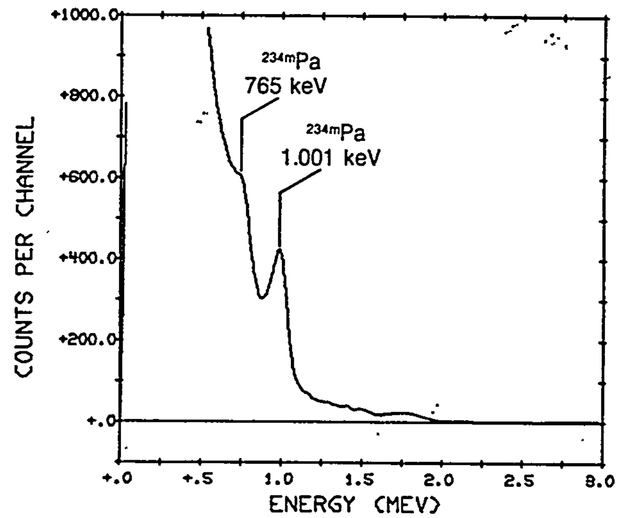
SPECTRUM NO. 198(22,26)-(32,36)
DATE 6/7/80
LIVE TIME (MIN) +.262
INTEGRATED CT. +.5460767E+06
TYPE ORNL,LINE=-23,HS NET
ALTITUDE 300 FT.
AIRCRAFT BO-105

Figure 27. *NET SPECTRUM FROM AREA 17*



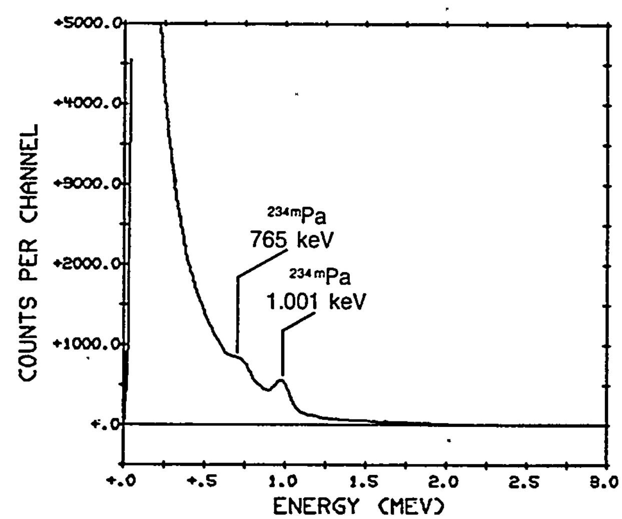
SPECTRUM NO. 206(20,24)-.62(33,39)
DATE 6/10/80
LIVE TIME (MIN) +.280
INTEGRATED CT. +.3939808E+06
TYPE ORNL,LINE=-27,*2HS NET
ALTITUDE 300 FT.
AIRCRAFT BO-105

Figure 28. *NET SPECTRUM FROM AREA 18*



SPECTRUM NO. 213(176,182)-(166,172)
DATE 6/10/80
LIVE TIME (MIN) +.373
INTEGRATED CT. +.6889822E+06
TYPE ORNL,LINE=-30,HS NET
ALTITUDE 300 FT.
AIRCRAFT BO-105

Figure 29. *NET SPECTRUM FROM AREA 19*



SPECTRUM NO. 206 (13,19)-(33,39)
DATE 6/10/80
LIVE TIME (MIN) +.364
INTEGRATED CT. +.7629251E+06
TYPE ORNL,LINE=-27,*1HS NET
ALTITUDE 300 FT.
AIRCRAFT BO-105

Figure 30. *NET SPECTRUM FROM AREA 20*

Table 5. Conversion Factors Relating Aerial Photopeak Count Rate Data to Radionuclide Concentration on the Ground for a Variety of Source Distribution Geometries

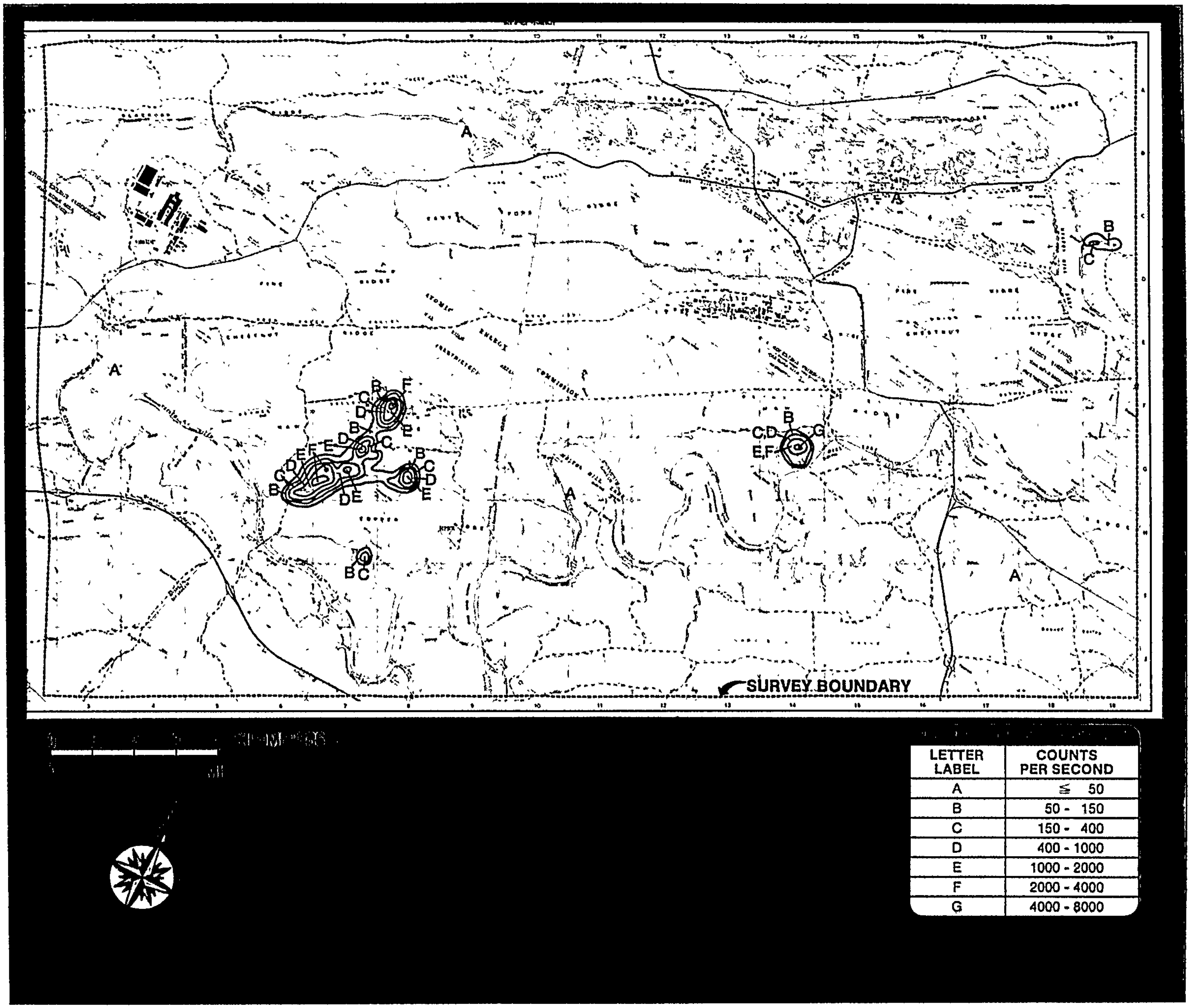
Radio-nuclide	Conversion Factor[a]: Point Source on Surface mCi/cps: Directly Under Aircraft	Point Source on Surface mCi/cps: At Lateral Displacement of 72 m	Uniform Surface Distribution: μCi/m²/cps	Uniform Surface Distribution: μR/h[b]/cps	Exponential Distribution: Relaxation Depth (cm)	Exponential Distribution: μCi/m²/cps	Exponential Distribution: μR/h[b]/cps	Uniform Volume Distribution: pCi/g/cps	Uniform Volume Distribution: μR/h[b]/cps
^{60}Co[c]	0.082	0.16	2.2 (10⁻³)	9.5(10⁻²)	0.1	2.2(10⁻³)	4.8(10⁻²)	2.8(10⁻²)	7.8(10⁻²)
					1.0	2.5(10⁻³)	6.3(10⁻²)		
					10.0	5.3(10⁻³)	5.2(10⁻²)		
^{234m}Pa[d]	11.6	23.8	0.33	1.4	0.1	0.33	1.4	4.4	8.8(10⁻²)
					1.0	0.38	0.5		
					10.0	0.84	0.1		
^{137}Cs	0.066	0.14	2.1 (10⁻³)	2.2(10⁻²)	0.1	2.1 (10⁻³)	1.9(10⁻²)	3.2(10⁻²)	2.0(10⁻²)
					1.0	2.5 (10⁻³)	1.6(10⁻²)		
					10.0	5.9 (10⁻³)	1.4(10⁻²)		

[a] Conversion factors are given for the twenty 12.7 cm × 5 cm NaI(Tl) detector array at an altitude of 91 meters, assuming an air density of 1.153 g/l and a soil density of 1.6 g/cm³ (10% soil moisture content). All results given are an average between those computed for an isotropic and for a cosine detector angular response.

[b] At the meter level, assuming a smooth air-ground interface (i.e., no surface roughness).

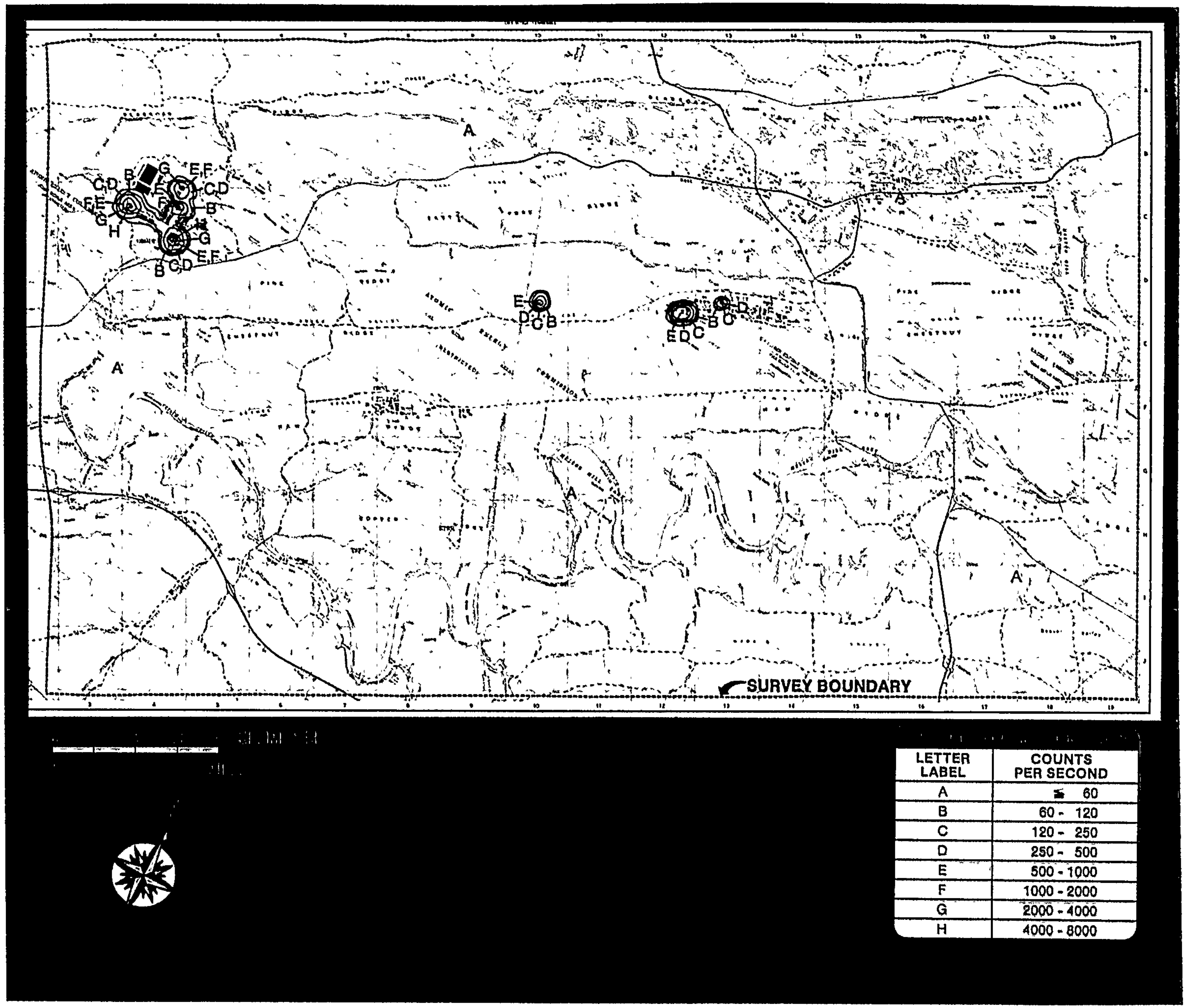
[c] 1.33 MeV photopeak

[d] 1.00 MeV photopeak



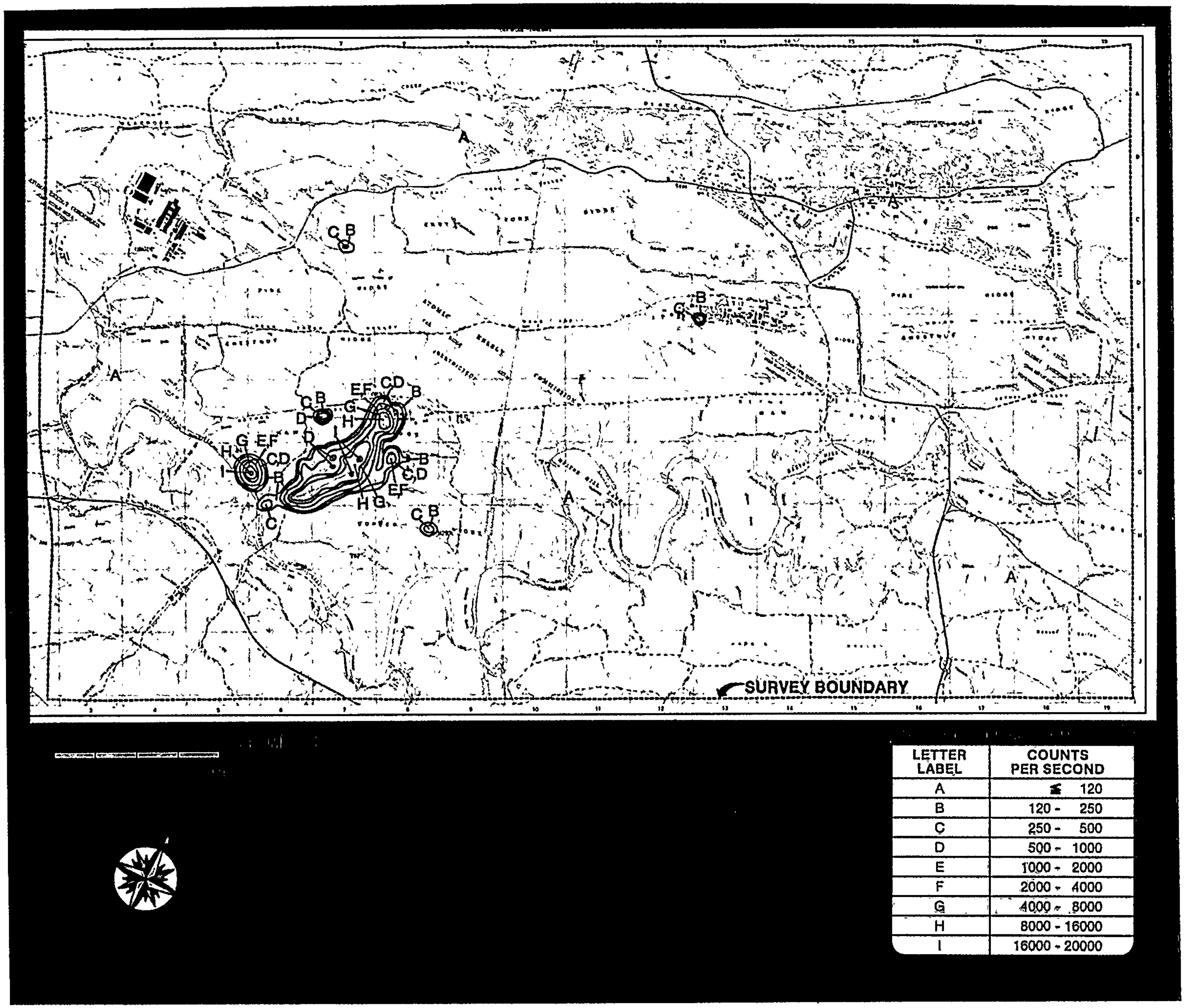
LETTER LABEL	COUNTS PER SECOND
A	≦ 50
B	50 - 150
C	150 - 400
D	400 - 1000
E	1000 - 2000
F	2000 - 4000
G	4000 - 8000

Figure 31. *^{60}Co PHOTOPEAK COUNT RATE ISOPLETH*



LETTER LABEL	COUNTS PER SECOND
A	≤ 60
B	60 - 120
C	120 - 250
D	250 - 500
E	500 - 1000
F	1000 - 2000
G	2000 - 4000
H	4000 - 8000

Figure 32. ^{234m}Pa *PHOTOPEAK COUNT RATE ISOPLETH*



LETTER LABEL	COUNTS PER SECOND
A	≤ 120
B	120 - 250
C	250 - 500
D	500 - 1000
E	1000 - 2000
F	2000 - 4000
G	4000 - 8000
H	8000 - 16000
I	16000 - 20000

Figure 33. ^{137}Cs PHOTOPEAK COUNT RATE ISOPLETH

REFERENCES

1. Burson, Z.G. February 1976. *Aerial Radiological Surveys of ERDA'S Oak Ridge Facilities and Vicinity.* Report No. EGG-1183-1682. Las Vegas, NV: EG&G/EM.

2. Biles, M.B., and Coffman, F. E. April 1974. "The United States Atomic Energy Commission Program for the Control, Monitoring and Reporting of Radioactivity in Effluents." Proceedings of the Second AEC Environmental Protection Conference, Vol. 1 WASH-1132(74), New Mexico.

3. Boyns, P.K. July 1976. *The Aerial Radiological Measuring System (ARMS): Systems, Procedures and Sensitivity.* Report No. EGG-1183-1891. Las Vegas, NV: EG&G/EM.